Meson Production and Bose-Einstein Pion Correlations in High Energy Collisions

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Abstract

The pion Bose-Einstein correlation parameters determined by OPAL show a weak dependence on pion multiplicity. We argue that the observed increase of the interaction radius, and the decrease of the chaoticity parameter could be due to an increasing fraction of other mesons at high multiplicities.

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Pion pair correlations[1] have been studied from high to low energies, some recent papers from which earlier references can be traced are [2] to [13]. The correlation function C_2 is

$$C_2(p,q) = W_2(p,q)/W_1(p)W_1(q) - 1 \tag{1}$$

where p and q are the momenta of two equal charge pions, $W_2(p,q)$ is the joint probability of finding one pion with momentum p and one of momentum q, while $W_1(k)$ is the probability of finding a single pion of momentum k. However, in the OPAL experiment[2] as in most other experiments the quantity studied is

$$R_2^{++/+-}(p,q) = W_2(p^+,p^+)/W_1(p^+)W_1(q^-) \tag{2}$$

which compares equal charge pion pairs with unequal charge pion pairs. If all degrees of freedom except the relative momentum[5] Q are summed over one obtains

$$R_2^{++/+-} \rightarrow R_2(Q^2) \tag{3}$$

which experimentally exhibits a peak at small Q^2. This peak is usually attributed to the Hanbury-Brown Twiss (H-BT) mechanism[1] according to which pions are emitted with random phases by a source of size R. The degree of chaoticity of the source is described by the parameter λ, where $0 \leq \lambda \leq 1$, and $\lambda = 1$ for a fully chaotic source.

Recently, the enhanced statistics of the OPAL measurements[2] at the Z^0 mass has allowed to study these correlation parameters as a function of charged multiplicity n, in the range $10 \leq n \leq 40$. It is found that the radius R at $n = 40$ is about 10 per cent bigger than the radius at $n = 10$. At the same time the chaoticity parameter decreases by about 15 per cent. These effects, while small, are statistically significant. We should also mention that detailed analysis of H-BT type intensity interference formulae for high multiplicities [14, 15] shows that the effective radius deduced from experiment tends to underestimate the true source radius. For the determination of R and λ, OPAL[2] has excluded the contributions from mesons and resonances decaying into pions, K^0, ω, η, η', ρ^0, $f_0(975)$ and $f_2(1270)$, at the corresponding high momentum transfers, while no cuts where applied below $Q \leq 0.3\ GeV/c$ where the H-BT peak occurs. Due to these cuts some (but not all) dynamical distortions which affect like and unlike charge pion pairs differently[1, 8] in R_2 are excluded and overall the chaoticity parameter λ becomes smaller than unity. Partly the reduction in λ is also due to experimental acceptance and vertex resolution effects. Similar reductions have also been observed at lower energies[6, 7]. In the OPAL analysis[2] the increase in source radius for increasing pion multiplicity has been linked to a larger fraction of three versus two jet events.

[5] The momentum transfer of two pions with four momenta p and q is defined by $Q^2 = M_{pq}^2 - 4m_\pi^2$ where M_{pq} is the invariant mass of the pion pair.

In this note we propose that a small increase of the fraction of primary mesons different from pions for high pion multiplicities would simultaneously explain both the behaviour of R and λ. We do not attempt to link our mechanism to a more microscopic picture. Our suggestion is presumably not in conflict with the observation of an increased fraction of three jet events at high multiplicities advocated by OPAL[2]. Our argument is straightforward: Since the observed source radii R in the correlation function R_2 are of order one fermi any mesons other than pions with long decay paths are introducing dynamical elements of coherence by propagating out of the source region. The number of primary pions is thereby reduced leading to a reduction of λ, and simultaneously the effective size of the pion source is expected to be increasing. Propagation effects have been considered previously[8, 16, 17]. We stress that the cuts in the analysis of OPAL[2] mostly exclude pion correlations from resonance decay while we now refer to correlations between one primary pion and a pion from a decaying meson. In order to produce the subtle effects observed in [2] it would be necessary that the f r a c t i o n of mesons different from pions increases for the observed range of multiplicities. We expect the strongest effect from fairly long lived mesons having long decay paths, like the omega meson for which $\Gamma^{-1} = 24\ fm$. The ρ meson is apparently not in this category, we should, however, remind the reader that no experiments so far have determined the true pion correlation function C_2, but rather the quantity R_2 has been measured. R_2 is a quantity that is much more sensitive to dynamical correlations, in fact it can be peaked at small relative momenta due to different slopes in Q^2 for like and unlike charge pion pairs while the true correlation function C_2 may have no peak at all. The fraction of ρ^0 mesons present in the sample will therefore affect R_2 by dynamical depletion of the unequal charge pion pairs at small Q^2, despite of the short ρ^0 life time. Bowler[17] has shown quantitatively for a chaotic string model that propagation effects lead to a larger radius R of the pion correlation function if a primary pion is combined with a decay pion from a meson resonance. The results depend on the meson resonance in question and on the experimental set-up.

Is there experimental evidence for an increase of the fraction of mesons as a function of multiplicity n? A direct experimental determination is not available. However, since for a fixed energy the total charged multiplicity is sharply peaked and the multiplicity is a well known function of energy, see Fig.4 in [18] and [19, 20] it is instructive to inspect the energy dependence of the production of mesons other than pions. Recent data for electron-positron annihilation have become very accurate. In Fig.3 of [21] there is clear indication that the average multiplicity of the vector mesons, ρ^0 and $K^\star$, per hadronic event, increases with energy. Denoting the average ρ meson multiplicity by $n(\rho)$ and the average charged multiplicity by n, as before, we read from the quoted figures $n(\rho) = 0.8$, $n = 13$ at 30 GeV, and $n(\rho) = 1.4$, $n = 20$ at 90 GeV. Similar results hold for the fairly narrow $K^\star$. It is plausible that other mesons (ω, K, η, η', etc.) show similar trends. Such behaviour could therefore partially explain the observed multiplicity dependence in [2]. Indeed if one calculates straightforwardly from the numbers given above the fractional population of ρ's at 30 and 90 GeV one can also estimate the derivative of this fraction with respect to multiplicity n to be roughly 1 per cent and POSITIVE. This value is slightly large when compared with the slope for the radius parameter R from OPAL[2] which is $1/\langle R\rangle \star dR/dn = (3.6 \pm 0.6) \times 10^{-3}$ for the Goldhaber parametrization. However, we must keep in mind that most of the propagation effects happen at very small momentum transfers, cp. Bowler[17]. In the OPAL experiment[2] the relative momenta are restricted to $Q^2_{exp} > (0.05GeV)^2$, and the effect is therefore expected to be diluted by the cut in Q^2 and by losses due to vertex resolution[22]. In other reactions, like multiple pion production in heavy ion collisions[23, 24], similar results are to be expected. Finally we would like to stress that the mechanisms suggested here for explaining the multiplicity dependence of the R and λ parameters do not necessarily depend on the stochastic picture for the pion emission region. All that is needed here is a nontrivial correlation function for the primary pion emission, be it C_2 or R_2. Nontrivial correlation functions can also be obtained by averaging procedures different from the stochastic H-BT model by various summations over unobserved variables which involve an entirely coherent basic pion-emission process[1, 8, 11, 12, 13] from more than one point source. From a theoretical point of view resonance effects can be treated in the Skyrmion picture[25] combined with the coherent state formulation of pion emission[12, 13], there may also be an interesting connection to squeezed coherent states[26, 27, 28].

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